LCA Methodology

A Simple Methodology for Elaborating the Life Cycle Inventory of Agricultural Products

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Abstract

Goal, Scope and Background. A methodological approach for representing agricultural products in terms of life cycle inventory is suggested in this paper. This approach was developed during the conduction of an LCA study for two perennial crops of important Brazilian exportation products: green coffee and orange juice, which included tillage cultivation by commercial farms, harvest, as well as product processing when pertinent.

The published papers on agricultural products LCA usually discuss the final results in terms of LCIA, being not very clear what methodology or principles were applied on the LCI phase. The aim of this paper is to present a simple methodology that would be employed by different stakeholders as farmers, environment managers and decision makers for evaluating the environmental performance of their products.

In recent years, many researchers have tried to make a worldwide effort in order to reach comparable results of LCA studies developed in different countries. So, the proposed methodology has also the aim of isolating the site-dependency of the results that are not strictly related to the agricultural production. The time coverage suggested is the period can be considered as an average for the specific tillage under evaluation, usually two crops, since there is a large variation on the inputs in every other crop, including the higher and subsequent lower productive periods.

Method. The functional unit recommended is 1,000 kg of the specific product, being recommended to distinguish the energy used for the cultivation from that used by the processing stage. There are several specific considerations to transform the data collected through the questionnaires in an inventory data set of fertilizers (macro and micro nutrients), correctives, fillers and pesticides further detailed. Water used for chemicals preparation, in the cleaning and processing stages of the harvested crop is also considered. Land use refers to the area used land for cultivation divided by the medium life period of the tillage.

The stoichiometric balance is performed based on the elementary composition of the products. An average carbohydrate formula is established for the products considering the relationship among the carbon, hydrogen and oxygen contents of them. The carbohydrate formula (output) is balanced with carbon dioxide and water (inputs) according to the basic principles of the photosynthesis reaction. The differences among the mineral composition of the products and the total content of these elements (N, P, K, Ca, Mg and micronutrients elements) for all the crop inputs (fertilizers, pesticides, correctives) are allocated as outputs of the system. The pesticides is counted in two forms: grouped in classes (herbicide, fungicide, acaricide, bactericide and inseticide) and specified by the chemical name of the active ingredient.

Results and Discussion. A simplified inventory useful for different purposes is generated with the principles described in this paper. The exact fate of each pesticide, fertilizer or corrective or assumptions can be further associated to impact categories as nutriphication, human health, natural resources depletion, ecological toxicity, etc. In this approach the mass balance was focused in the grain or fruit growth and not in the plant or tree as a whole, considering basically the elementary composition of the product and the photosynthesis principle. Despite agricultural LCAs performed in different countries have been published, neither of them considers the carbon capture by the agricultural products during their growth.

Conclusions. This method is based on well accepted universal principles of stoichiometry applied to the grain or fruit growth. Minimum estimations were introduced in this approach, which produces 'clean inventories', with comparable results between different studies. The generated inventory can be gradually improved as the understanding about each emission fate is known, producing a valid methodology for actual and future knowledge about the fate of tillage emissions. The inventory results of this method can be employed by different stakeholders as farmers, environment managers, decision makers and traders, with valuable environmental parameters for evaluating the environmental performance of their products and also for introducing improvements on their systems, without however to exhibit any particular data.

Keywords: Agricultural products; Brazil; fruit; grain; life cycle inventory (LCI); methodology

Introduction

The increasing environmental awareness of consumers in a great number of countries all over the world requires a more deep knowledge concerning the environmental impacts of the usual agricultural activities. A meaningful part of agricultural products are cultivated in regions or countries different from that they are effectively consumed. At the moment, the trading of these products does not consider neither the cost of land use and its transformation nor the use of chemicals or fertilizers on the environment. It is necessary to establish a simple reference guide for the agricultural products in order to include the environmental aspects of their tillage in the trading activities.

LCA of industrial production systems is quite established since LCA was developed primarily for evaluating the environmental performance of industrial products. LCA applied

to agricultural production is a more recent area and then some new approaches are missing since there are remarkable differences between the industrial and the agricultural production systems. For instance, the land use is usually ignored for industrial systems, while it is essential for agricultural ones. Besides the soil quality can change due to the agricultural production with physical changes which alter ecosystems and affect biodiversity and aesthetic value of landscape (Cowell and Clift 1997).

Different from the industrial production, the mass balance can only be reached in an LCA of agricultural product if it is considered the carbohydrate production that takes place from capture of CO_2 during the photosynthesis reaction during the growth of the product itself (vegetable, grain, fruit, etc) otherwise the equilibrium between the inputs and outputs will not be reached.

There are less papers on LCA studies for agricultural systems than for the industrial systems since this is a relatively new area of LCA application. One of the most relevant contribution on agriculture LCA was published by Weidema and Meeusen (2000) in 'Agricultural data for Life Cycle Assessments'. Many aspects of this publication were considered in the present paper, but the approach proposed here is different from that, being a quite simplified method for being creating a useful dataset for different stakeholders in the agricultural chain and not only for LCA experts.

1 Goal and Scope

The initial objective of this study was to apply LCA for two important Brazilian exportation products: green coffee (Coltro et al. 2006) and orange juice. The published papers on agricultural products LCA studies usually discuss the final results in terms of LCIA, being not very clear what methodology or principles were applied on the LCI phase. It was difficult to find a clear methodological approach based on the life cycle principles that could be employed in this study.

Therefore, the objective of this study is to present a simple methodology that would be employed by different stakeholders as farmers, environment managers and decision makers as a reference for perennial crops evaluation.

Other important aspect is that the proposed methodology can be improved as the knowledge about the fate of the crop emissions increases. This approach includes the crop cultivation stages that happens in commercial farms, i.e., harvest and the processing stages, the last one applied for some agricultural products, e.g. product drying.

In recent years, many researchers have made an worldwide effort in order to reach comparable results of LCA studies developed in different countries. Therefore, the proposed methodology has the aim of isolating the site-dependency of the results that are not strictly related to the agricultural production.

1.1 System boundaries

In order to attend the proposed goals, it is recommended the inclusion of the following stages in the called 'basic agricultural inventory':

1) the cultivation stage considering the plants in production phase, of every other crop in order to account periods of low and high yields
2) all inputs added during the the time covered by the study, considering only their quantity but not the whole life cycle of them
3) all the energy inputs for the agricultural machineries as well as the human labour
4) the processing stage of the product inside the farm, when pertinent.

Besides the basic inventory data the following parameters can be evaluated separately:

- The inclusion of the whole life cycle of fertilizers, correctives and pesticides that are available, clearly identified;
- Storage and distribution of the agricultural products, since these data are directly dependent on the distribution distances of each farm / country.

1.2 Time and geographical coverage

Agricultural products have the harvest time concentrated in few months of the year and an oscillating productivity every other year. For instance, coffee has the harvest time concentrated between the months May and September and an yield profile composed by an year with high yield followed by a subsequent year with low yield.

Then, the time coverage suggested is the time that can be considered as an average for the specific tillage under evaluation, usually two crops, since there is a large variation on the energy inputs, fertilizers and pesticides consumed, etc. every other crop.

The time coverage should also considers the crop rotation since this is an efficient technique for reduction of the fertilizers requirement as well as in the control of pest and diseases.

The most important areas for the studied tillage should be defined taking into account the production and distribution geographical maps of the country considering also the product variety.

2 Methodology

2.1 Data collection

An specific questionnaire should be elaborated for collecting the agricultural product growing data. Whenever possible it is important to fulfill the questionnaire by personal interviews in order to facilitate the obtainment of the answers and reliable data.

The questionnaire should include questions about all the inputs like fertilizers, correctives, pesticides, water usage, diesel, natural gas, electric energy, etc. used in the time coverage considered in the study.

Information about product distribution until the exportation harbor should also be requested: truck type and total distance traveled as well as the exportation countries.

Other aspects of the tillage like general data of the farm, total area , effectively cultivated area, density of plants, cultivated varieties, crop and harvest management types, number of employees should also be collected.

Type of soil, altitude, climatic conditions as annual pluviometric and solar radiation indexes can be further associated to the generated inventory.

2.2 Functional unit

The functional unit recommended, as the most LCA studies is 1,000 kg of the specific product. Sometimes, it is useful to convert the mass reference in a unit based on the commercial package as 1,000 green coffee bags (60,000 kg) or 1,000 orange boxes (40,800 kg), by helping farmers in planning their crops.

A second functional unit based on the cultivated area, like 1 hectare (kg/ha) can be used in order to express the use of inputs by cultivated area.

Besides these functional units Milá i Canals (2003) suggested the inclusion of differences in quality characteristics (size, external and internal quality) in the definition of a functional unit when this is considered to be relevant. In this case, the allocation procedure should be consistent with the goal of the study.

2.3 Principles for the mass balance of agricultural products

2.3.1 Carbohydrate balance

The stoichiometric balance was performed for the green coffee grain and the orange based on their elementary compositions. An average carbohydrate formula was established for these both products considering the relationship among the carbon, hydrogen and oxygen contents of them. The minimum formula of the balanced carbohydrate, $C_nH_yO_z$ (output) was balanced with carbon dioxide and water (inputs) according to the basic principles of the photosynthesis reaction.

Balanced basic photosynthesis reaction:

$$nCO_2 + \frac{y}{2}H_2O \rightarrow C_nH_yO_z + (n + \frac{y}{4} - \frac{z}{2})O_2$$

It is important to consider the exactly elementary composition of the grain or fruit being studied taking into account the dry weight of the grain or fruit in the form it really leaves the agricultural property, in other words, after the processing stage.

The miminum carbohydrate formula can be obtained from elementary composition of the crop product by calculating of the C/H, C/O and H/O molar fractions.

This methodology considers only the parts of the marketable plant (the product itself) for the mass balance so that the final inventory reflects the environmental cost for the production of this product. This is the same concept used in industrial system, which the capital investments are not considered.

Nevertheless, for studies that focus on the carbon captured by the plant (carbon credit), the whole plant should be considered and not only the grain or the fruit.

2.3.2 Mineral balance

The differences between the mineral composition of the product and the total input of these elements (as N, S, P, K, Ca, Mg, B, Cu, Fe, Mn, Zn and minor constituents) in the evaluated crops as fertilizers, chemicals and correctives were allocated as outputs of the systems.

Considering the carbohydrate and the mineral balance of the grain or fruit by the method proposed in this paper it is possible to equilibrate the mass balance in the cultivation stage.

Since in this approach the mass balance was focused in the grain or fruit growth and not in the plant or tree as a whole, measurements or estimations should be accomplished when the objective is to evaluate how many of these elements were: a) absorbed by the plant, b) retained into the soil, c) leached by the rain, d) evaporated, as well as what are the chemical reactions of each one of these inputs.

2.4 Energy requirements

It is important to evaluate the requirement of energy by the system, being recommended to distinguish the energy used for the cultivation stage from that used by the processing stage. So, they are expressed separately.

The energy used in the cultivation refers to the necessary energy for the operation of the agricultural machineries for preliminary and primary soil preparation, seeding, fertilizing, farm operations and harvesting. The energy consumed in the processing stage accounts the necessary energy for the product washing, cleaning or drying processes.

Detailed discussion about energy use in agricultural systems can be found in the literature (Audsley, Nielsen and Luoma, Villox and Michot, Moerschner and Gerowitt and Cortijo in Weidema and Meeusen (2000).

2.5 Chemicals

The following step is to transform the data collected through the questionnaires in an inventory data. This stage is not frequently discussed in scientific publications and can generate significant differences in the results. Therefore, some guidelines are proposed for the elaboration of these inventories.

The use of electronic spreadsheets can precede the introduction of the data in an specific LCA software. Every stage should be indeed balanced. It is recommended to associate each input to a final destiny in each stage considered.

In the sequence, considerations accomplished for important items of these inventories are detailed.

Macronutrients. They are chemical elements necessary in large amounts, usually greater than 1 ppm in the plant, considered for the growth of plants like nitrogen (N), phosphorus (P) and potassium (K). The total amount of these elements that are added during the whole crop were summed and separated by their organic or inorganic sources.

Micronutrients. Each culture demands essential mineral elements besides the macronutrients for its development and growing that are usually present in the elementary composition of the fruit. The essential micronutrients considered for coffee, for instance, are the bore (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). Other tillages demand different micronutrients for plant nutrition and they should be identified and discriminated.

Correctives. The application of the corrective agents promotes neutralization of the soil acidity. The main elements considered for this purpose are calcium (Ca) and magnesium (Mg).

Fillers. The fertilizers, acting as macro or micro nutrients, and correctives are provided by many formulations, simple or complexes. In order to identify the quantity of fillers that are added in a crop, it is important to specify the brand name of the source of each of these elements. One of the main impacts from the traditional farming is the soil mineralization.

Pesticides. The pesticides used for controlling pests in plants (and in their products) and for preventing their spread were identified by their chemical names being the content of the remaining formulation called as filler of the brand name of the pesticide. In agriculture language, fillers are often called 'inert' but this term can not be considered appropriate since many of these substances are solvents or surface tension agents.

Besides, the specification of the brand name allows to establish a historical perspective of the use of each product. Manufacturers of the pesticides will be able to evaluate their market share among the farms appraised. One of the current goals in agricultural researches is to reduce to total amount of this kind of products as well as their toxicity levels. Inventories elaborated in this way can be useful for these important actors of the agricultural chain.

The pesticides were classified according to the international regulations. The CAS number (Chemical Abstracts Service) was also associated to each declared ingredient in order to identify exactly the added component. The most usual classes considered for tillages are Fungicide, Herbicide, Inseticide, Bactericide and Acaricide.

Narayanaswamy et al. (2004) adopted this approach in his LCA case studies for Australian grain products except by the filler content specification in the LCI. Since the filler is not exactly 'inert' due to its mineralization potencial it is suggested in this paper to account also the filler in the LCI of agricultural products. So, it will be possible to evaluate its impact when more information concerning its effects on the environment be available.

Example for introducing chemicals in the LCI:

The addition of 2,761 kg of the pesticide commercialized as Roundup WG (with 72% of active ingredient), declared in the questionnaire is transformed in the following inventory items:

Glyphosate, CAS 1071-83-6 (Herbicide)	= 1987.92 kg
Filler (Roundup WG, commercial registration)	= 773.08 kg
Herbicide	= 1,987.92 kg excl. (excluded from the mass balance)

Chemicals allocation. The mass balance proposed here refers to the product(s) of the agricultural activity. So, when more than one marketable product is obtained in the same crop, the chemicals allocation should be made considering the proportion of each product, as well as its commercial value.

2.6 Water and land use

The water used for the dilution of the chemicals as pesticides, for cleaning and required in the processing stage of the harvested crop is counted in this item. The water consumed for the growth of the plants, although of fundamental importance for the growing, is quite difficult to estimate and it is not usually considered in the inventories of agricultural products.

The use and the transformation of the land for the agricultural cultivation are among the subjects of larger importance in this study area. The theme is quite wide and has been discussed in depth by several researchers as the Hemeroby concept (Bentrup 2002) that measures the human influence on ecosystems and the guidelines for the application of the concepts of land use, land-use change and forestry – LULUCF (IGES 2003).

In the simplified inventory proposed in this paper, only the area of the land divided by the medium life period of the tillage is considered. This period of time covers from the plantation, growth, productive period until the complete removal of the trees.

2.7 Crop characterization

As a function of the site-dependency of the agricultural systems to the climatic conditions, soil composition and agricultural management practices, it is crucial that the following characteristics be clearly associated to the results of any study: plant varieties, density of plants, types of soil, seeding, manual or mechanical harvesting, pluviometric and solar radiation indexes, etc.

The labour hours used in each crop give an indirect measure of mechanization level of the farm and it is a key issue for social discussions around the world and of great importance for agricultural countries.

3 Environmental Impacts

Agricultural inventories can be associated to several categories of environmental impacts. The main impact categories usually associated to agricultural activities are nutriphication, energy consumption, human toxicity, ecotoxicity, natural resources depletion, soil mineralization, erosion and land use. In this way, there are several papers in the literature with estimations for the environmental impacts of agricultural products (Zalidis et al. 2002, Weidema 2001, Brentrup 2000, Halberg et al. 2001).

4 Inventory Disclosure

One of the main difficulties found in LCA studies is that many of the supplied data are confidential and their publication may reveal specific aspects of the technology used. A great number of these studies must not be made publicly available, a fact that hinders decision makers for applying the best possible management.

Trying to reconcile the different stakeholders involved in this process, an inventory proposal was elaborated (**Tables 1** and **2**), where valuable environmental parameters are shown, without however disclosing any particular data. In this sense it is also usual to publish average data instead of single one. This inventory proposed here does not represent a complete balance. The complete balance, containing the exact chemicals and commercial names will be used for internal purposes only and is not made available.

Table 1: Example of the inventory generated by the proposed method

Parameters	Unit	Average (kg/t)	Average (kg/ha)
Input			
Energy			
Total	MJ		
for cultivation	MJ		
for processing	MJ		
for transport of the chemicals	MJ		
Other Resources			
Water for product processing	kg		
Fertilizers			
Total (actives and fillers)	kg		
N, P, K (macronutrients)	kg		
B, Cu, Fe, Mn, S, Zn (micronutrients)	kg		
Pesticides			
Total (actives and fillers)	kg		
Fungicide	kg		
Herbicide	kg		
Inseticide	kg		
Bactericide	kg		
Acaricide	kg		
Acaricide/ Inseticide	kg		
Correctives			
Total (actives and fillers)	kg		
Ca, Mg	kg		
Land Use			
Land use	ha.yr		
Output			
Organic residue used as fertilizer	kg		
Waste water	kg		

Table 2: Example of parameters used to characterize the crop

Parameters	Unit	Average
Productive plants	Plants	
Density	Plants / ha	
Yield	Ton / ha	
Pluviometric index	Mm / year	
Solar radiation index	MJ / m^2.day	
Labour	labour hours / ton	
Plant varieties		
Soil classification		
Crop rotation	Comments about tillage sequences, period, etc.	
Main agricultural management practices	Comments about seeding type, soil preparation, soil covering, irrigation system, manual or mechanical harvesting, characteristics of the processing, etc.	

5 Conclusions

This method is based on well accepted universal principles of stoichiometry applied to the grain or fruit growth. Minimum estimations were introduced in this approach, which produces 'clean inventories', with comparable results between different studies. The generated inventory can be gradually improved as the understanding about each emission fate is known, producing a valid methodology for actual and future knowledge about the fate of tillage emissions. The inventory results of this method can be employed by different stakeholders as farmers, environment managers, decision makers and traders for evaluating the environmental performance of their products and also for improving the systmes through implementation of better practices, with valuable environmental parameters, without however to disclose any particular data.

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